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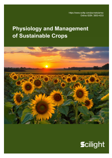

Article

Nutritive Value of *Corchorus olitorius* Leaves as a Potential Poultry Feed in Tropical Semiarid Regions

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Abstract: Advocacy for using indigenous plants as livestock feed is growing, especially for poultry production in developing countries that are challenged by increasing ingredient importation costs. *Corchorus olitorius* is an underutilized plant broadly adapted globally between 50° N & S that is used widely as a leafy vegetable crop; however, little is known about the nutritional value of *C. olitorius* for poultry feed. Consequently, *C. olitorius* leaves were collected from multiple sites in three diverse regions of Botswana in 2025 to evaluate the nutritive value of native and improved ecotypes, with each site having 3 replicates in a completely randomized design. Leaves of *C. olitorius* contain sufficient levels of crude protein (CP) (205–313 g kg^{-1}), fat (17–39 g kg^{-1}), and several essential minerals to potentially minimize the amount of supplementation necessary from imported sources, but crude fiber (CF) levels (46–128 g kg^{-1}) would require management to prevent that interfering with digestion. Consequently, leaves of *C. olitorius* may be of value for burgeoning poultry industries; however, excessive Fe content of *C. olitorius* leaves would need to be addressed in any ration but may present an opportunity for utilization as an organic feed supplement.

Keywords: *Corchorus olitorius*; alternative feed; broiler chickens; poultry; native plants

1. Introduction

The demand for human dietary protein is increasing with the rise in global population [1–3], thus calling for increased production of protein sources. This also has its own challenges. Animal-based protein production costs are increasing with changes in land use that also lead to increased feed crop production costs [1]. Poultry production is viewed as critical to addressing food security concerns in developing countries [3] and, thus, is the most rapidly growing sector of animal production [2]. Although it is mainly on a subsistence level at the present time, commercial production is limited by socio-economic and environmental issues [2]. Still, poultry production is considered the most efficient mechanism to supply human protein requirements in developing countries, as well as a potential source of income for subsistence farmers [2,3]. Chicken meat already comprises the highest proportion of per capita meat consumption in Africa due to affordability and nutritional quality consistency compared to other meats [2], and it is gaining in popularity in Africa and other continents [3,4].

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Bird performance and egg quality are the main factors affecting poultry income [5]. Poultry feed cost represents >70% of total production costs [2,3]. Many of the main ingredients of poultry feed are also used for human food, creating a conflict in utilization and increasing feed costs for poultry [2,3]. Knowledge about poultry nutrition consistently evolves, encompassing novel feed formulations, nutrient utilization efficiency, and the integration of precision nutrition strategies to optimize production while reducing costs and environmental impact [1,6]. Mineral nutrition has not been adequately evaluated; however, it is known that several micronutrients are required for broiler and laying hen nutrition, but most feedstuffs do not contain adequate amounts, so supplementation is usually necessary [7]. Intestinal health is also a major concern in poultry production, particularly in regard to pathogens, including issues with antibiotic resistance [2,8]. Many plants contain nutraceuticals that boost feed efficiency and mitigate the use of antibiotics [2].

Similarly to many other feed components used for any livestock or poultry enterprise, many developing countries cannot produce either cereals or soybean (*Glycine max*) meal in mass quantities, thereby increasing the cost of production [1,2] through importation [6] or limiting the amount provided to meet dietary requirements [9]. Consequently, many countries are trying to reduce input costs by using more locally available sources, including native plant species [2,6,9]. The 50N to 50S latitudes globally have many underutilized plant species that can serve as locally-grown feeds [2]. New feedstuffs are being evaluated to reduce production costs, but they vary regarding any safety concerns [10] and nutritional quality [2,3,9,11].

Corchorus olitorius is native to tropical and subtropical regions of Africa and Asia across a broad range of weather conditions [12,13]. It grows as an annual or short-lived perennial that volunteers in abandoned fields and grasslands and is a common weed of disturbed or cultivated areas, although it is also planted as a fiber crop and safely used as a human vegetable [13–16].

As with most areas of livestock production, numerous knowledge gaps exist in poultry nutrition, from determining the most optimum levels of supplementation for various nutrients to finding lower-cost feed ingredients. Locally sourced ingredients can be used to address forage breeding and cultivation techniques to meet challenging conditions faced by developing nations. *C. olitorius* has not been evaluated as a locally available, potentially low-cost poultry feed ingredient. Therefore, the objective of the present study was to evaluate tropical African ecotypes of *C. olitorius* leaves grown in three diverse ecosystems for their potential as poultry feed based on proximate analysis and mineral content.

2. Materials and Methods

2.1. Site Descriptions and Sampled Materials

One to three sites in three diverse regions (districts) of Botswana were used in 2025 to evaluate the nutritive value of native ecotypes *C. olitorius*. District locations are shown in Figure 1 and site-within-district characteristics are shown in Table 1.

Table 1. Characteristics of sites where various ecotypes of *Corchorus olitorius* leaves were collected in Botswana in 2025 for evaluation as poultry feed. All soils from the sampled sites were sandy loam to fine sandy loam soils.

Variable										
District		**Northeast**			**Central**			**Southern** [1]		
Site(s) [2]	**1**	**2**	**3**	**4**	**5**	**6**		**7–11**		
Place of origin		Botswana			Botswana		Botswana	Cameroon	Mali	Sudan
Latitude of origin	20.53S	20.57S	20.59S		22.55S		7, 8: 24.66S	9: 7.37S	10: 12.86N	11: 17.57N
Elevation of origin, m	1310	1300	1266		919		1014	500	343	375
Weather [3] (October through April during the rainy season)										
Mean temperature (°C)		22.5			23.1		19.5			
Total precipitation (mm)		355			351		327			
Soil characteristics										
pH	6.0	5.4	5.0	5.9	6.2	6.7	6.1			
TDS, mg kg^{-1}	49	50	51	45	44	44	52			
Organic C g kg^{-1}	2.9	4.3	2.9	4.5	4.1	4.5	2.8			
Available N, mg kg^{-1}	0.4	0.4	0.5	0.7	0.6	0.5	0.2			
Available P, mg kg^{-1}	3.3	4.9	2.3	7.6	8.9	5.9	10.2			
K, mg kg^{-1}	70	203	78	156	137	148	161			
Ca, mg kg^{-1}	714	540	182	1396	1614	1500	237			
Mg, mg kg^{-1}	112	244	66	104	101	12	125			
Na, mg kg^{-1}	0	0	0	9.2	6.9	2.3	1.8			

[1] The southern sites were different ecotypes from various places of origin planted in the same field as part of another study in Botswana. [2] The numbers 1 to 11 in the site and latitude of origin rows pertain to the site numbers assigned in Tables in Section 3. [3] Weather data were sourced from the Botswana Meteorological Service (https://gov.bw/index.php/environmental-management/request-climatological-data; accessed 13 June 2026).

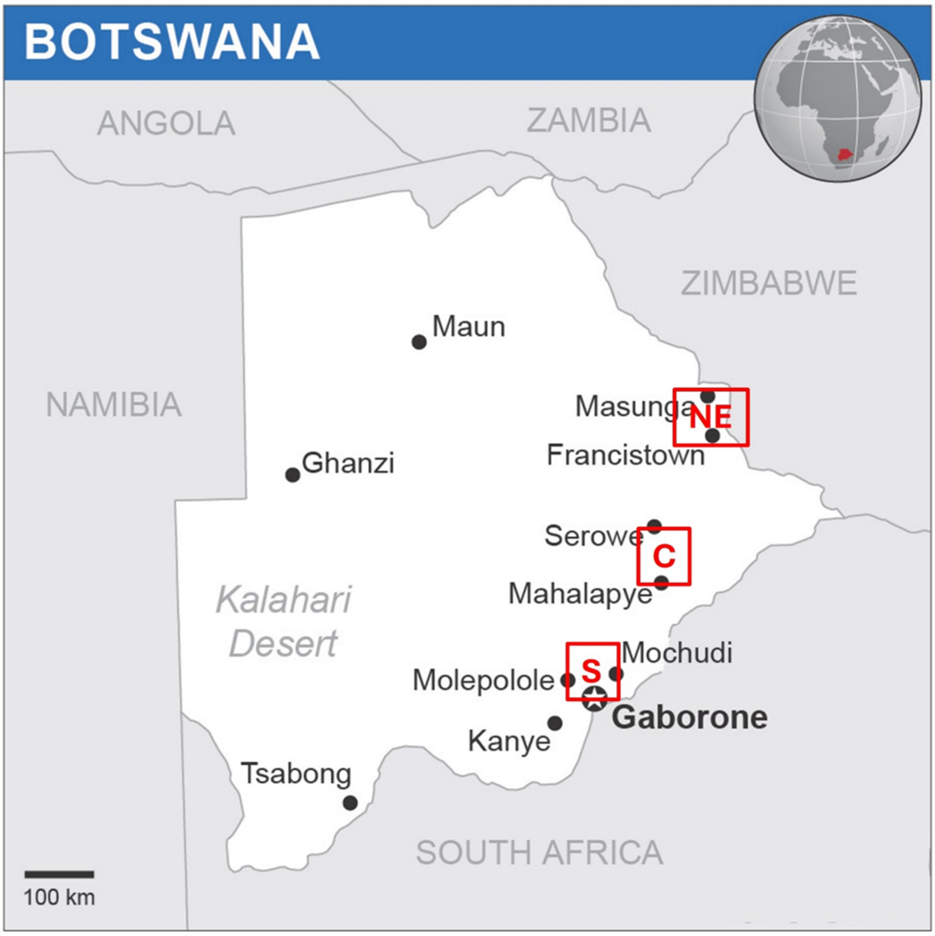

Figure 1. Locations in Botswana where *Corchorus olitorius* leaves were collected for evaluation as a potential poultry diet ingredient in 2024–2025. NE, C, and S signify northeast, central, and southern, respectively. (Based on OCHA, free original or modified map used permitted: https://www.unocha.org/publications/map/botswana/botswana-location-map-2013; accessed 11 July 2026).

All soils from the sampled sites were sandy loam to fine sandy loam soils. The northeast and central sites were private land of different farmers. Southern sites 7 & 8 were ecotypes from the southern district and from other tropical African nations, including Cameroon (9), Mali (10), and Sudan (11). These were planted in the same field and soil type as part of a larger study at the Botswana University of Agriculture and Natural Resources Research Farm near Gaborone. All sites were rainfed, and no fertilizers or pesticides were applied to any site during the study period. The *C. olitorius* used in the Central and Northern Districts were local ecotypes, while the accessions used in the Southern District were sourced from the Botswana National Genetic Resource Centre (Delele 1, MSB072) and the World Vegetable Centre, Regional Gene Bank, Tanzania, with accessions from Cameroon (Bafia), Mali (Local Leave), and Sudan (SUD3).

2.2. Sampling and Measurements

All mature expanded leaves of *C. olitorius* were collected by hand from a 0.25-m^2 quadrat during the vegetative stage from three replicates at each site. This was done during the wet season (mid-December to mid-February) as the plant exhibits rapid growth and short maturation cycles (40–60 days for leaf harvest). After collection, leaves were oven dried for 48 h at 65 °C and ground to pass a 5-mm screen using a Pulverisette 16 beater mill (Fritsch Cross, Pittsboro, NC, USA) prior to being sent to Ward Laboratories (Kearney, NE, USA) where final milling took place for proximate analysis (AOAC method 990.03 for crude protein, CP, [17]; AOCS Ba 6a-05 method for crude fiber, CF [18]; and AOCS Am 5-04 method for fat [19]) and evaluation of mineral content (Ca, P, K, Cu, Mg, Mn, and Mo [20]). The Ca:P ratio was calculated for each sample as Ca divided by P.

2.3. Statistical Description

The *C. olitorius* leaf proximate analysis (CP, CF, and fat) and mineral (Ca, P, K, Cu, Mg, Mn, and Mo) content data were analyzed using the mixed procedure of SAS version 9.4 [21] to compare District and the site-within-district interaction. The three replicates within each site were treated as a completely randomized design uniquely identified within each site. site-within-district and replicates within site-within-district were considered random, while District was a fixed effect being selected to represent different environments within semiarid tropical Africa. All differences reported are significant at $p \leq 0.05$ and when the F-test for District or the site-within-districtinteraction was significant ($p \leq 0.05$), lsmeans were compared by least significant differences using the SAS PDMIX800 macro [22].

3. Results and Discussion

3.1. Proximate Analysis

The main effect of District was significant for all proximate analysis variables (Table 2).

Table 2. Proximate analysis of *Corchorus olitorius* leaves from multiple sites (ecotypes) in three districts in Botswana in 2025. Values are the lsmeans of three replicates within each site-within-district.

District	Site	CP [1]		CF		Fat	
		g kg^{-1}		g kg^{-1}		g kg^{-1}	
Northeast	----	268	A [2]	99	AB	34	A
Central	----	211	B	106	A	31	A
Southern	----	234	AB	51	B	23	B
Site-within-District							
Northeast	1	261		88		33	
	2	313		81		36	
	3	230		128		35	
Central	4	221		106		32	
	5	205		96		20	
	6	207		116		39	
Southern	7	245		56		27	
	8	228		46		26	
	9	254		49		24	
	10	211		50		17	
	11	232		52		22	
		p-values					
District		0.0208		0.0062		0.0009	
Site-within-District		0.3871		0.3954		0.1181	

[1] CP and CF signify crude protein and crude fiber, respectively. [2] District or Site-within-District lsmeans within a column followed by similar letters are not significantly different based on a 5% LSD. A lack of letters indicates nonsignificance based on the *p*-value.

Except for CP, values decreased or tended to do so from north to south. The CP at the central site was least, with the southern district intermediate, but the central sites had the greatest CF, with northeast being intermediate. Fat in the southern district was less than the northeast and central sites, which were not different (Table 2). No differences existed among sites within any district for any variable of proximate analysis. Differences among districts for each variable (Table 2) may be due to lower temperatures and precipitation during the growing season at the southern district compared to the other two districts (Table 1). *C. olitorius* grows well in lowland tropics, up to an elevation of 1250 m, and performs well in areas with rainfall of between 600 and 2000 mm/year [14] (Table 1). It is tolerant of different soil types with a pH ranging from 4.5 to 8.2 [15], but it grows best in mineral-rich soil that is well-drained. Clay soils are not suitable due to waterlogging conditions [13]. The optimum temperature for growth and development is 25 to 32 °C (Table 1), but it can tolerate temperatures from 20 to 40 °C [14].

The CP measured in the present study was well within the range of levels reported in the literature for complete poultry diets [9,23–27], but much less than the 310 g kg^{-1} used by Yu et al. [4]. Adhikari et al. [1] stated that birds do not have a particular requirement for CP, but that the proportion of some essential amino acids was important [6,28]. Therefore, the amount of CP in the diet could potentially be reduced based on meeting the requirement for the lower limiting essential amino acids [1,6]. The most used dietary ingredients for poultry include most of the necessary amino acids [1], and several individual amino acids are available for supplementation to reduce the overall level of CP in the diet. Feeding excess CP leads to compromised intestinal health [1], foot problems [1,29], and environmental pollution [6]; however, reducing the CP content too much (by more than 20–30 g kg^{-1}) can reduce broiler performance, even if amino acids are balanced [1]. As poultry matures, the CP content of their feed generally decreases, and the energy content increases [1], but the CP content of up to 21-day-old broilers can be reduced to as low as 150 g kg^{-1} when the amino acid proportion is considered and supplemented as needed [28].

Reduced CP in the ration should possibly be balanced by reduced energy (fat and digestible fiber) to avoid excessive accumulation of abdominal fat [1]. Excess energy can also lead to heat stress in poultry [1], which is a serious concern for poultry production during summertime, especially in birds selected for increased growth rates and bodyweights [24]. Future research evaluating *C. olitorius* should include determining its amino acid profile and digestibility of individual amino acids [6,28] to minimize excessive feeding.

The CF of *C. olitorius* leaves measured in the present study (Table 2) was considerably higher than that used elsewhere in basal diets for broiler chickens [8], except for the southern district where it was only slightly higher than those reported elsewhere. High dietary CF can lead to reduced nutrient digestion [2,9], but it also would lead to reduced competition for feedstuffs between humans and livestock [9]. Schedle [9] reported that digestive fermentation of non-lignified materials is much higher than lignified materials. Although not measured in the present study, the lignin content of leaves would be considerably less than stems, thereby being more digestible. Perhaps finer grinding and pelleting [6] would help with this concern regarding fiber [9] by reducing gizzard retention [30]. Incorporating high-fiber feed ingredients, such as *C. olitorius*, at lesser proportions in the diet also would dilute their CF content and mitigate other potential anti-quality factors [2].

The fat measured in *C. olitorius* leaves in the southern district was significantly lower than in the other districts (Table 2). Fats measured from the northeast and central districts in the present study were consistent with those used in maize (*Zea mays*)–soybean meal–oat (*Avena sativa*) basal diets for grower (4 to 8 weeks) and developer (8 to 16 weeks) laying pullets [26]. But they were less than that provided to starter pullets (0 to 4 weeks: 53.5 g kg^{-1}) by Jing et al. [26] and Nguyen et al. [9] for broiler diets. Generally, recommendations are to include at least 10 g kg^{-1} of fats in the diet, although 20–50 g kg^{-1} are usually included depending on the relative costs of fat and grain ingredients [31]. Including >40 g kg^{-1} may decrease the quality of pelleted feeds [31]. Energy is a required nutrient for growth and maximum performance, being supplied largely by supplemental fats and oils because their energy value is twice that of carbohydrates and protein [31]. Additionally, insufficient energy content in feed has been associated with increased foot problems in poultry due to increased CP and mineral intake [29]. Hence, fat levels for poultry energy requirements are a concern, especially regarding fat digestibility [6,31], and is of significant economic importance [32] due to cost [31], although the energy value of fats is difficult to evaluate [31]. This should be a focus of future research, including the digestibility of plant-based fats in native plants, such as *C. olitorius*, and other local sources. Plant-based oils are often added to poultry diets [8,23–27,31,33], and using plant fats has been shown to reduce the saturated fat content of poultry meat compared to tallow [31]. Additionally, saturated fats inhibit lipase activity compared to unsaturated fats, as well as influencing mineral availability in the digestive tract [31]. Fatty acid composition is an important consideration in the choice of which fat sources to use [31]. Consequently, future research on *C. olitorius*, or any potentially new feedstuff should also include an evaluation of the fatty acid proportions. Otherwise, *C. olitorius* presents an opportunity to develop a new CP and fat source for poultry diets in the challenging conditions faced by developing countries.

3.2. Minerals

For minerals, no differences were observed among districts or sites within any district for Fe (790 ± 399 mg kg^{-1}), Na (1.04 ± 0.05 g kg^{-1}), or Zn (31 ± 8 mg kg^{-1}), with the Fe content being considerably higher than maize gluten (277 mg kg^{-1}) and soybean meal cake (263 mg kg^{-1}) [7]. The Fe provided in complete diets reported in the literature were 50 [33], 80 [23], and 40 [8,25] mg kg^{-1}. Recommendations for Fe in poultry diets range from 50 to 100 mg kg^{-1}; however, supplementation to 200 mg kg^{-1} in the diet was sufficient to increase edible poultry Fe content by 13–39%, depending on the muscle or organ location [7]. Consequently, the Fe levels measured in *C. olitorius* leaves in the present study could be excessive as a major feed ingredient although *C. olitorius* leaves could be considered as an organic Fe supplement. The Na level found in the *C. olitorious* leaves in the present study (1.04 g kg^{-1}) was within the range used in various poultry diets of 1.0 to 2.5 g kg^{-1} [4,27,33]), which indicates a potential need for supplementation from other sources. Otherwise, high dietary Na and Cl reduce intake and increase dropping moisture content [4] and, thus, litter moisture contributing to foot problems [29]. Zinc is essential for many functions including enzymatic activity immunity, and offspring performance, as well as an antioxidant. Breeder hens require 50 mg kg^{-1} [34] and deficiency is observed at <10 mg kg^{-1} in the diet [7]. The Zn provided in complete diets reported in the literature was 110 [33], 40 [23], and 60 [9,25]. The Zn measured in the present study would prevent deficiency, but at 31 mg kg^{-1} would not be sufficient to meet the optimum requirement; however, supplementation is typically used to meet the requirements because basal diets reported in the literature were often low [34]. High Zn in the diet (150 mg kg^{-1}) coupled with high biotin (2000 ppb) potentially reduces foot problems [29].

The Zn and Fe provided in the da Cruz Ferreira Junior et al. [23] study were approximately 40 and 80 mg kg^{-1}, respectively. Supplementations of Zn and Fe by Nguyen et al. [8] and Hu et al. [25] were 60 and 40 mg kg^{-1}, respectively, and by Berwanger et al. [33] they were 110 and 50 mg kg^{-1}, respectively.

Results for other minerals tested are shown in Table 3. All minerals except the Ca:P ratio had differences among districts, and all but K and Cu had differences among sites within at least one district, which is likely related to soil conditions since within each district, the sites were in close proximity and would have experienced similar weather.

Table 3. Mineral content of *Corchorus olitorius* leaves from multiple sites (ecotypes) in three districts in Botswana in 2025. Values are the lsmeans of three replicates within each site-within-district.

District	Site	Ca		P		Ca:P		K		Mg		Cu		Mn		Mo	
		g kg^{-1}		g kg^{-1}		ratio		g kg^{-1}		g kg^{-1}		mg kg^{-1}		mg kg^{-1}		mg kg^{-1}	
Northeast	----	16.3	A [1]	5.6	A	3.3		36.4	A	3.07	AB	9.3	A	108	B	1.38	A
Central	----	16.9	A	5.3	A	3.8		28.4	B	3.32	A	6.7	B	68	C	1.77	A
Southern	----	6.9	B	2.2	B	4.0		24.2	C	1.59	B	7.5	B	129	A	0.28	B
Site-within-District																	
Northeast	1	13.4	B	7.5	A	1.8	B	39.4		2.73		8.3		171	A	0.15	B
	2	15.8	B	3.3	C	4.9	A	33.2		3.33		9.8		90	B	0.26	B
	3	19.6	A	6.2	B	3.3	AB	36.7		3.13		9.6		63	B	3.74	A
Central	4	15.1		5.7	A	2.8	B	29.8		2.90	B	5.7		75		2.67	A
	5	16.8		6.2	A	2.9	B	29.2		2.70	B	6.9		62		1.57	B
	6	18.7		4.0	B	5.9	A	26.3		4.37	A	7.4		66		1.05	B
Southern	7	9.3		2.0		5.5		23.2		1.53		7.1		112	B	0.19	
	8	6.1		2.0		4.1		21.0		1.63		7.0		109	B	0.44	
	9	7.5		2.5		3.6		26.7		1.57		7.8		153	A	0.16	
	10	6.6		2.3		3.7		26.2		1.73		8.7		149	AB	0.40	
	11	5.2		2.2		3.3		23.8		1.47		7.1		122	B	0.20	
p-values																	
District		<0.0001		<0.0001		0.4477		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
Site-within-District		0.0072		0.0005		0.0153		0.1207		0.0137		0.8035		<0.0001		<0.0001	

[1] District or Site-within-District lsmeans within a column followed by similar letters are not significantly different based on a 5% LSD. A lack of letters indicates nonsignificance based on the *p*-value.

Calcium is the most abundant mineral in many animals, with nutritional deficiencies readily evident [30,35] since it is essential for bone growth and other functions [35]. The Ca measured in *C. olitorius* leaves in the present study (Table 3) was considerably greater than levels used in basal diets reported elsewhere for poultry [8,27], similar to other reports [23] in the southern district, but about half that reported in some studies [33]. Dietary sources of Ca are inexpensive [35]. Consequently, Ca is often overfed to prevent deficiencies, although that can also interfere with P digestion [30,35] as well as other minerals [35], thereby leading to environmental pollution from that nutrient [6,35]. Because birds selectively ingest Ca [35], thorough mixing of feeds, as done by pelleting [6], may be appropriate to avoid over-ingestion, as could be the case with loosely mixed feeds with whole or large leaf fragments, such as provided by *C. olitorius* [14].

The P levels in the northeast and central districts were greater than those in the southern region (Table 3) and generally sufficient to meet P provided in basal diets used by other researchers [23,24,26,27,33]. Based on soil P levels (Table 1) and plant P levels (Table 3), we speculate that there was no connection between plant P levels and soil P levels among sites in this study (Tables 1 and 3). Perhaps the soil P contents were sufficient to meet the uptake demands for the local ecotypes. Supplemental P is the third most expensive nutrient in poultry diets [6,35]. Dietary P was provided to broiler breeding hens and chicks at 4.5 g kg^{-1} [27,33], which is fairly accepted as a general requirement for broilers of all ages. In addition to skeletal effects, dietary deficiency in P enhances susceptibility to heat stress [26]. Excessive P in the diet not only increases feed costs [36], but it also has negative environmental consequences when overfed [26].

Based on the content in bone, which is where 99% of Ca is used [35] and 85% of P is used [26], Bedford and Rousseau [30] stated that the Ca:P ratio should be about 2:1, which is considerably less than that in most *C. olitorius* leaves in the present study (Table 3). Consequently, supplementation with a greater available P source would be necessary when using *C. olitorius* in the diet. The cereal grains most often used in broiler diets contain greater amounts of P and less Ca [35] to accommodate dilution of the Ca:P ratio in *C. olitorius*. Otherwise, plant-based P from grains other than maize is highly available to young chicks [6]. The P availability in legume grains and oilseed meals also is low [6]. Supplementation with sodium monophosphate can be used to adjust P levels to meet a 2:1 Ca:P ratio in poultry diets [35]. That would also supplement low Na in *C. olitorius* to meet that requirement.

The K content of *C. olitorius* leaves in the present study (Table 3) is about twice the recommended amount (15.3 g K kg^{-1}), likely causing increased water consumption [29]. Yu et al. [4] reported that 1.0 g NaCl kg^{-1} was sufficient to optimize weight gain and blood Na and K levels, as well as water intake. However, excessive Na and K (3.1 g Na kg^{-1} and 15.3 g K kg^{-1}) in poultry diets increased water consumption to the point of increasing litter moisture and, hence, the severity of foot problems in poultry [29].

Magnesium is considered a macro-mineral, along with Ca, P, S, Na, Cl, and K, for food-producing animals, including poultry, as a cofactor in hundreds of enzymes in animals, with supplementation recommended above the requirement levels to improve meat quality and egg production [36]. Most complete poultry feed ingredients likely include enough Mg to avoid deficiency; however, supplementation may be used to design diets for maximum performance, especially in light of increased performance of modern poultry [6,36]. Increases in feed conversion ratio of 57% in the recent past likely has changed the dietary requirements of many minerals, such that current recommendations for poultry are 0.5 g Mg kg^{-1} after 3 weeks of age [36], which is considerably less than that found in *C. olitorius* leaves in the present study (Table 3). Otherwise, overfeeding Mg can lead to diarrhea as one of the first symptoms, followed by reduced intake and performance [36] and has been implicated in wet litter, which increases the likelihood of foot problems in poultry [29]. Because of interactions with Ca and P absorption, close attention to variation in dietary Mg is necessary as overfeeding may disrupt P absorption and reduce Ca content in eggshells [36] because it competes with Ca in absorption and binds with it to reduce availability to poultry [35]. That could also help reduce the Ca:P of *C. olitorius* leaves (Table 3), however.

Essential trace minerals that are usually supplemented for poultry include Cu [6,7,33], Fe, Mn, Zn, Se, and I [6,7]. The latter two minerals were not evaluated in the present study, and results for Fe and Zn have been previously reported in this section.

Poultry requirements for Cu are low (12.5 mg kg^{-1} for breeding hens [33] and 11.3 [25] to 14 [37] mg kg^{-1} for growing broilers), although recommendations have been less at 8 mg kg^{-1} [8,25,27,33,37]. The *C. olitorius* leaves at many of the sites in the present study either approached or equaled those Cu levels, particularly in the northeast district (Table 3). Copper has a role in enzyme-related metabolism [27,37], including Fe absorption and hemoglobin production and embryo development [33]. Organic Cu sources led to greater feed conversion ratios compared to an inorganic form ($CuSO_4 \cdot 5H_2O$), providing 9.87 and 8.84 mg kg^{-1}, respectively [23]. These differences were associated with P, Zn, and Fe metabolism [23,37]. Organic Cu forms were also presumed to increase serum CP in broilers and may support protein synthesis in muscles [23]. Deficiency is uncommon, despite the Cu content in many plant-sourced feeds being low due to soil depletion by intensive farming [33]. Overfeeding is often done at 100–300 mg kg^{-1} as an antibiotic and to promote growth through improved gut health and nutrient absorption [9], as well as for cholesterol reduction and immunity [7,27]. In some cases, overfeeding has led to environmental pollution [24,27]. Greater amounts of Cu have been associated with poor performance of broilers [9]. Antioxidant effects of diets [2], including mitigation of heat stress [1,24] are improved by Cu supplementation since Cu is coupled with Zn for enzymatic activity [24]. In addition to being associated with Zn absorption, Cu improves Fe metabolism as well as the activities of many enzymes [25] and has positive influences on beneficial microbial populations and is antagonistic against diseases. The benefits of antioxidants are more important for poultry than beef or pork because poultry meat is more sensitive to oxidation [7,8,24], thereby potentially mitigating over-use of antibiotics for pathogen control as well as for promoting growth [8].

Manganese is required for many aspects of poultry production from reproduction to performance [5]. The current recommendation for dietary Mn is 40 and 60 mg kg^{-1} for laying hens and broilers, respectively, but recent research suggests that it should be 90 mg kg^{-1} for both classes of poultry and that supplementation >180 mg kg^{-1} increased various aspects of performance, while >400 mg kg^{-1} Mn had a negative effect [5]. The Mn measured in the present study for *C. olitorius* leaves (Table 3) is similar to that provided in complete diets elsewhere (120 [33], 103 [23], 110 [25], and 80 [8] mg kg^{-1}) and would, consequently, meet the current recommendation when grown at all sites. However, the more recent recommendations, even approaching 180 mg kg^{-1} [5], would be met only at some of the northeastern and southern sites. Organic Mn sources are more bioavailable than inorganic sources; however, most plant-based sources are low in Mn content [5]. Both Mn and Zn are necessary for proper bone development and an observed increase in tibia content indicated a reduced antagonism during digestion when organic Cu was fed [23]. Factors limiting availability include dietary Ca, P, and CF [5]. Therefore, use of *C. olitorius* leaves as a significant ingredient in poultry diets may be beneficial, as reported by Mnisi et al. [2] for leaf meal from sources, depending on the CF content of other feed ingredients and based on the levels measured in this study (Table 2).

The high genetic variability *C. olitorius* [38] allows it to be adapted in different environments between 50° N & S and has been introduced throughout those regions of the western hemisphere as well (https://www.picturethisai.com/wiki/Corchorus_olitorius.html, accessed 4 October 2025). Perhaps the environment of origin (Table 1) led to different Mn uptake mechanisms that became a component of their genetic makeup. *C. olitorius* originating from equatorial regions, such as Cameroon, as well as some ecotypes from sites and districts within Botswana (Figure 1; Tables 1 and 3), may have a greater genetic potential for increasing certain minerals in the plant, which would allow for breeding programs to address the challenges of meeting forage demands for poultry feed ingredients across a range of environments.

Results for the Mo content in *C. olitorius* leaves across a range of tropical latitudes are reported in Table 3. Nys et al. [7] stated that Mo may be potentially essential; however, no literature was found reporting feed ingredient levels, requirements, or dietary levels fed in research. Differences existed between districts and sites within the northeastern and central districts of Botswana, but soils analyses did not include Mo levels to attribute the differences to soil characteristics, although soil pH at site 3 was considerably lower than at all other sites (Table 1).

Inorganic forms of mineral supplements are known to have low nutrient availability [7,24]. Hence, organic forms have been widely studied and developed for more efficient availability [6,7,34]. Perhaps natural forms in plants, such as *C. olitorius*, will also be more bioavailable forms of minerals. Future research should evaluate the bioavailability of minerals for poultry. Improvement in nutrient use efficiency in livestock feeding is a major challenge in meeting the demand for animal protein by a growing human population [9]. Avoiding excessive inclusion of some dietary ingredients is more environmentally friendly regarding greenhouse gas emissions [9], increasing the level of some soil nutrients to toxic levels when manure is applied [7], and polluting surface and groundwater sources [6]. A balanced poultry diet with minimal oversupply of some nutrients, including minerals, is important for maintaining litter quality to prevent footpad problems, which is a major concern influencing bird performance and economic returns [29]. Otherwise, some locally sourced plants may contain anti-quality factors that interfere with poultry health and productivity [2]. Hence, future studies on *C. olitorius* leaves should include evaluations of such compounds as tannins, saponins, oxalates, phytates, and alkaloids [2] because many of these phytochemicals have been found in a qualitative screening of mature *C. olitorius* leaves [14].

Many feed ingredients are available to provide the nutritional requirements of poultry; however, in many developing countries, major ingredients must be imported, thereby increasing production costs. Evaluating locally sourced ingredients are critical to the increasing poultry industries in these regions. *Corchorus olitorius* is a broadly adapted species that could be used to overcome some of the economic hurdles of low-input poultry production that challenges developing countries to find new forage crops with potential for genetic improvement.

4. Conclusions

This study suggests that some of the nutrients measured for leaves of *C. olitorius* may potentially provide sufficient levels to minimize the amount of supplementation necessary from other sources (e.g., 205–313 g crude protein kg^{-1}, 17–39 g fat kg^{-1}, along with several essential minerals, with relatively low crude fiber content for vegetative plant material at 46–128 g kg^{-1}, although, that is still greater than recommendations for poultry diets). Therefore, leaves of *C. olitorius*, a native or introduced plant in numerous developing countries within the 50° N & S latitudes, contain many nutrients of potential value for burgeoning poultry industries making it a resilient, locally-based feed ingredient under challenging conditions of low ingredient availability in developing countries and high costs of imported ingredients. Excessive Fe content of *C. olitorius* would need to be addressed in any ration but may present an opportunity for utilization as an organic feed supplement. Using *C. olitorius* leaves as a mineral supplement, thereby, limiting its proportion in the diet would mitigate the excessive Fe and fiber content for poultry but take advantage of its positive attributes regarding other minerals as well as protein and fat.

Many research gaps remain in poultry nutrition, as well as in how newly evaluated feed ingredients can be used to meet poultry requirements. *C. olitorius* falls into the latter category to determine appropriate supplementation levels, including amino acid and fatty acid proportions and anti-quality factors. Another research need is to develop management strategies for cultivation, harvesting, and processing for large-scale commercial production. Otherwise, breeding improvement opportunities, feed safety, and supplementation levels must still be evaluated, as do commercial production and processing methods to meet challenging conditions for forage production in the future.

Author Contributions

Conceptualization, L.M.L. and S.B.P.; methodology, L.M.L., M.A.M. and S.B.P.; software, L.M.L.; validation, L.M.L. and S.B.P.; formal analysis, L.M.L. and S.B.P.; investigation, S.B.P.; resources, L.M.L., N.K. and S.B.P.; data curation, L.M.L. and S.B.P.; writing—original draft preparation, L.M.L. and S.B.P.; writing—review and editing, L.M.L., G.M., G.D.H., N.K., M.A.M., S.O.T. and S.B.P.; visualization, L.M.L. and S.B.P.; supervision, L.M.L., G.M.,

G.D.H. and S.O.T.; project administration, L.M.L., G.M., G.D.H. and S.O.T.; funding acquisition, L.M.L. and N.K. All authors have read and agreed to the published version of the manuscript.

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Not applicable.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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